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Brief Report

Standardized standing pelvis-to-floor photographs for the assessment of lower-extremity alignment

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SUMMARY

Objectives: The objective of this cross-sectional study was to assess the intra-rater, inter-rater and test-retest reliability and concurrent validity of lower-extremity alignment estimated from a photograph [photographic alignment (PA) angle].
Methods: A convenience sample of participants was recruited from the community. Radiopaque stickers were placed over participants' anterior superior iliac spines. One radiograph and one photograph were taken with the participant standing in a standardized position. The stickers were removed. After 30 min they were reapplied and a second photograph was taken. The hip-knee-ankle (HKA) angle was measured from each radiograph using customized imaging analysis software. The same software was used by three readers to measure the PA angle from each photograph from the first set twice, at least 2 weeks apart. One reader measured the PA angle from the second set of photographs. Reliability was tested using intraclass correlation coefficients ($ICC_{(2,1)}$), Bland–Altman analyses and the minimal detectable change (MDC_{95}). Concurrent validity was tested using a Pearson's correlation coefficient and Bland–Altman analysis.
Results: Fifty adults participated (mean age 41.8 years; mean body mass index 24.7 kg/m^2). The PA angle was 4.5° more varus than the HKA angle; these measures were highly correlated ($r = 0.92$). Intra-rater ($ICC_{(2,1)} > 0.985$), inter-rater ($ICC_{(2,1)} = 0.988$) and test-retest reliability ($ICC_{(2,1)} = 0.903$) showed negligible bias (<0.20°). The MDC_{95} was 2.69°.
Conclusions: The PA angle may be used in place of the HKA angle if a bias of 4.5° is added. A difference of 3° between baseline and follow-up would be considered a true difference.

Introduction

Malalignment of the lower extremities (LE) is one risk factor for knee osteoarthritis (OA), a common cause of pain and physical disability in older adults[1]. Therefore, it is important to accurately assess frontal-plane LE alignment. The "gold standard" measure of frontal-plane LE alignment is the hip-knee-ankle (HKA) angle, measured from a full-length LE radiograph[2]. The HKA angle is at the intersection of a line drawn from the center of the femoral head through the center of the knee (femoral axis) with a line drawn from the center of the knee through the center of the ankle (tibial axis). Varus angles are denoted in negative degrees and valgus angles are positive[2].

Full-length LE radiographs are not always available to determine the HKA angle. Stated reasons include expense, lack of specialized equipment and concern over ionizing radiation[3]. There is a need for an accurate way to estimate the HKA angle easily, without using radiographs. Prior research using small numbers of young, healthy adults suggests that this angle may be estimated from a pelvis-to-floor photograph [photographic alignment (PA) angle][4,5]. The objective of this study was to determine the intra-rater, inter-rater and test-retest reliability and concurrent validity (correlation to the HKA angle) of the PA angle in a larger number of adults, with a range of ages and body mass index (BMI) scores representative of the general population.

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Participants and methods

The study was approved by the University Health Sciences Research Ethics Board.

Participants

Fifty adults who could stand without assistance for 20 min were recruited from the community between April and November 2012. This sample size enabled an adequate distribution of BMI and alignment. Potential participants were not accepted if they had a recent traumatic injury to the LE or contraindications to radiography. Participants gave informed consent.

Measurements

Standing full-length LE radiograph

One weight-bearing, full-length LE anteroposterior digital radiograph was taken in a standardized position [Fig. 1(A)]. Each participant, dressed in shorts and in bare feet, stood on a calibrated template placed on a step-stool. Heels were positioned 9 cm apart and the lower limbs were rotated such that the axis of knee flexion was in the frontal plane[6]. Foot rotation was recorded from the template. Circular stickers (1.9 cm) with radiopaque beads taped to the center were placed on the skin over the anterior superior iliac spine (ASIS) bilaterally.

An OPTIMA XR640 X-ray machine with a 40.3 cm-by-40.3 cm digital detector (General Electric, model #2393824) was used. Three or four individual radiographs were taken and “stitched” together using software.

Standing pelvis-to-floor LE photograph

Two photographs were taken with the participant in the same standardized position. A Canon PowerShot SD800IS (Cannon Canada Inc., Mississauga, ON) digital camera (7.1 megaPixels) was attached to a tripod with the lens of the camera positioned at the participant's knee joint line, 3.0 m from the participant.

Procedure

At the first testing session one photograph and one radiograph were taken, in random order. The stickers were removed and the participant changed back into street clothes. After 30 min the stickers were reapplied and a second photograph was taken, following the same protocol.

Customized imaging analysis software (Surveyor™ image analysis program 3.1, Orthopedic Alignment and Imaging Services, Inc.) was used to analyze the radiographs and photographs. Hip, knee and ankle points were identified manually and the software calculated the HKA and PA angles. Three readers were trained to use the software.

Right and left knees were assessed. All images were randomized separately for each instance of reading. The radiographs were assessed for the HKA angle. The photographs taken in the first testing session were assessed for the PA angle by three readers twice each, at least 2 weeks apart. The photographs taken in the second session were assessed once. Readers were blinded to prior HKA and PA angle determinations.

Determination of the HKA angle

The HKA angle was calculated as the angle between a line drawn from the center of the femoral head to the tibial interspinous groove and a line drawn from the tibial interspinous groove to the center of the tibial plafond [Fig. 1(B)][3]. Intra- and inter-rater reliability calculations for the HKA angle were intraclass correlation coefficient (ICC) > 0.995[7].

Determination of the PA angle

The PA angle was calculated as the angle between a line from the estimated center of the hip (32% of the inter-ASIS distance medial

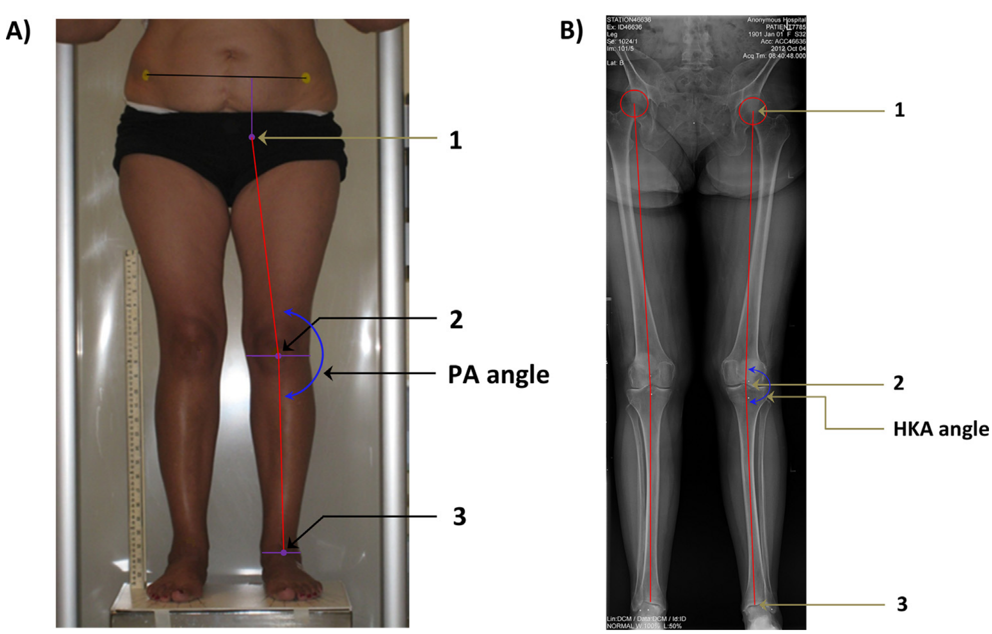

Fig. 1. Participant set-up and lower-extremity angle calculations. (A) The PA angle, measured from a pelvis-to-floor photograph. 1. Estimated center of the hip [32% of the inter-ASIS distance medial to, and 34% of this distance distal to the ASIS]. 2. Estimated center of the knee (the mid-point of a horizontal line drawn across the knee where the medial contour of the soft tissue of the knee changes from convex to concave). 3. Estimated center of the ankle (the mid-point of a line drawn horizontally at the crease where the ankle meets the foot). (B) The HKA angle, measured from a full-length LE radiograph. 1. Center of the femoral head. 2. Tibial interspinous groove. 3. Center of the tibial plafond.

to, and 34% of this distance distal to the ASIS[8]) to the estimated center of the knee (the mid-point of a horizontal line drawn across the knee where the medial contour of the soft tissue of the knee changes from convex to concave[5]) and a line from the estimated center of the knee to the estimated center of the ankle (the mid-point of a line drawn horizontally at the crease where the ankle meets the foot) [Fig. 1(A)].

Data analysis

Analyses were performed using Minitab (version 15.1.30.0, Minitab Inc., State College, PA) and MedCalc (version 12.2.1.0, MedCalc Software, Mariakerke, Belgium). Statistical significance (the probability of making a Type I error) was set at alpha = 0.05. There were no missing data.

$ICC_{(2,1)}$ and Bland–Altman analyses were used to assess intra-rater reliability of the PA angle between reading times one and two for readers one, two and three, individually[9,10]. $ICC_{(2,1)}$ was also used to assess inter-rater reliability between readers one, two and three for reading time one. Additionally, Bland–Altman analyses were used to assess inter-rater reliability between each pair of readers for the first reading time. $ICC_{(2,1)}$ and Bland–Altman analyses were used to assess test-retest reliability between PA angle readings from the first and second testing sessions. Bland–Altman analyses were used to explore variation in the application of the testing procedure between assessment sessions and in the angle determinations within or between readers. The minimal detectable change at the 95% level (MDC_{95}) was calculated[11].

The relationship between the HKA and PA angles (concurrent validity) was examined using a Pearson's correlation coefficient and Bland–Altman analysis. Gender difference was evaluated.

Results

Participants

Fourteen males and 36 females participated, with a mean age of 41.8 years (range 20–86) and a mean BMI of 24.7 kg/m^2 (range 17.1 kg/m^2–37.2 kg/m^2). The mean PA angle was −5.0° (range −12.7° to −3.4°); the mean HKA angle was −0.4° (range −8.9° to −7.4°). Analyses for right and left knees were not significantly different; data for the right knee are presented.

Reliability of the PA angle

Reliability results are presented in Table I. Intra-rater, inter-rater and test-retest reliability were excellent, with high correlations, no discernible bias and narrow limits of agreement. The SEM for test-retest reliability was 0.97° and the resulting MDC_{95} was 2.69°.

Concurrent validity between the HKA and PA angles

The Pearson's correlation between the HKA and PA angles was 0.92 ($P < 0.0001$). The PA angle was an average of 4.5° more varus than the HKA angle, with limits of agreement between −6.9° and −2.1°. There was no proportional bias (see Supplementary Figure For Bland-Altman Plot) or gender difference.

Discussion

The PA angle estimated using the selected points had excellent intra-rater, inter-rater and test-retest reliability. Furthermore, the PA and HKA angles were highly correlated, with the PA angle 4.5° more varus than the HKA angle.

Table I
$ICC_{(2,1)}$ and Bland–Altman analysis results for intra-rater, inter-rater and test-retest reliability for the PA angle (right knee)

	$ICC_{(2,1)}$ (95% confidence interval)	Bland–Altman bias (°)	Bland–Altman limits of agreement (°)
Intra-rater reliability			
Reader 1	0.995 (0.991, 0.997)	−0.10	−0.68, 0.46
Reader 2	0.985 (0.974, 0.991)	0.01	−1.08, 1.09
Reader 3	0.996 (0.993, 0.998)	−0.01	−0.56, 0.54
Inter-rater reliability			
Readers 1 & 2	0.988 (0.981, 0.993)	0.06	−1.02, 1.15
Readers 1 & 3		0.01	−0.86, 0.88
Readers 2 & 3		−0.05	−0.92, 0.81
Test-retest reliability			
Photographs 1 & 2	0.903 (0.835, 0.944)	0.20	−2.4, 2.9

The knee, ankle and proximal femoral axis points chosen to determine the PA angle were supported by the strong reliability and concurrent validity results. Determination of the knee and ankle points directly on the photograph produced the least variability and makes it unnecessary to use skin markers, making the procedure more convenient. The proximal femoral axis point is simple to determine as the ASIS is easy to palpate. This point is not altered by rotating the LE, so it may be placed before the participant is positioned on the foot template.

Reliability results for the PA angle were similar to or higher than those reported from similar studies performed on small numbers of young, healthy participants (ICCs of 0.627–0.997 for intra-rater reliability, 0.827–0.989 for inter-rater reliability and 0.700–0.904 for test-retest reliability)[4,5]. The reliability of the PA angle was similar to that of the HKA angle (intra-reader reliability ICC 0.998; inter-reader reliability ICC 0.995)[12].

There were several potential sources of variability between readers and reading times, for example glare from the camera flash, body hair and body habitus. Despite this, ICC results were consistently 0.99 for intra-rater and inter-rater reliability. No bias for reliability was found, which confirmed that our readers did not alter their technique between readings. The narrow Bland–Altman limits of agreement confirmed the small amount of variability between reading sessions and among readers.

Test-retest reliability may be affected by additional potential sources of variability, such as clothing, LE positioning, placement of the stickers and camera set-up. There was no bias in the test-retest reliability data, which indicates that the protocol was consistently followed. The Bland–Altman limits of agreement confirm a small amount of variability between testing sessions.

The PA angle was highly correlated to the HKA angle. Schmitt *et al.*[5], using a sample of 10 individuals with moderate BMI (19–28 kg/m^2) also found a very high correlation (Pearson $r = 0.98$, $P < 0.001$) between the PA and HKA angles, with the PA angle 0.9° more varus than the HKA angle. We show similar results in a larger and more-varied sample. The MDC_{95} was 2.69°, so a difference of 3° between individuals or between baseline and follow-up would be considered a true difference.

Standardization of the testing position was very important. Changes in limb rotation and foot position can alter the HKA angle[2,5,6]; therefore, these parameters also need to be controlled in the determination of the PA angle. Prior studies using photographs had participants stand in a self-selected position, in the Romberg stance position (with medial borders of feet touching), with feet pointing straight forwards or in 30° external rotation[4,5]. None of these positions account for the variability among individuals with respect to rotation of the femur and tibia. Others use anatomical landmarks based on such features as the patella and the tibial tubercle; these too can vary among individuals[6]. To accommodate between-participant variability, we used a template to position participants with their heels a consistent 9 cm apart, and altered the foot position so that the axis of rotation for knee flexion was in the frontal plane[6].

Customized digital software was used to analyze the radiographs and photographs. This software provided tools to measure distances and calculated the HKA and PA angles. Other studies have magnified the photographs and used a goniometer to measure the PA angle[4,13]; however, using digitized software has been shown to improve precision and reliability for the calculation of the HKA angle[14,15].

There are some limitations of this study and a few areas to investigate further. It must be emphasized that we chose a hip point that was not located over the center of the femoral head. The photographs and radiographs used for this study could be used for future investigation on how to best estimate the location of the center of the femoral head on a photograph. Also, while we had a broad range of individuals with respect to age and BMI, our sample is not comprised of individuals at particularly high risk of knee OA. Nonetheless the reliability findings suggest that the photographic method could be used to measure frontal-plane LE alignment in populations deemed at risk for knee OA. A longitudinal study of individuals at high risk for progression of varus or valgus deformity, or pre- and post- LE realignment surgery, should be performed to study the sensitivity to change of the PA angle.

In conclusion, the PA angle can be used in place of the HKA angle, without the cost, ionizing radiation or inconvenience associated with full-length LE radiography. The correlation between the PA and HKA angles is high, however, the PA angle is 4.5° more varus and this bias must be accounted for when estimating the HKA angle.

Authors' contributions

The authors have made substantial contributions to the following:

L Sheehy: the conception and design of the study, acquisition of data, analysis and interpretation of data, drafting the article and revising it critically for important intellectual content. She gave final approval of the version to be submitted.

TDV Cooke: the conception and design of the study, interpretation of data and revising the article critically for important intellectual content. He gave final approval of the version to be submitted.

L McLean: the conception and design of the study, interpretation of data and revising the article critically for important intellectual content. She gave final approval of the version to be submitted.

E Culham: the conception and design of the study, analysis and interpretation of data and revising the article critically for important intellectual content. She gave final approval of the version to be submitted.

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Competing interest statement

TDV Cooke is the president of Orthopedic Alignment and Imaging Services, Inc., which provided the imaging analysis software free-of-charge. There are no other conflicts of interest to declare.

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Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.joca.2014.12.009.

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